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Research Article

STRATEGIC MANAGEMENT DISCOURSE OF TOP-LEVEL MANAGERS: AN ANALYSIS OF THE MARITIME INDUSTRY IN TÜRKİYE

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ABSTRACT
Today's complex and challenging business environment compels decision makers to respond to emerging issues, making strategic management is a critical factor for maritime organisations and businesses. Their survival depends on the ability to successfully craft, pursue, and implement effective strategies. Despite its crucial role in the maritime industry, the literature lacks sufficient documentation of decision makers' perceptions, approaches and practices related to strategy. This study addresses this gap by analysing top managers' strategic management discourse. Using a dataset of 68 published interviews, the authors employed deductive content analysis based on a novel strategic management keyword dictionary. This process identified 56 keywords categorised under six distinct themes: Government and Markets, Positioning, Performance, Growth, Technology, and Human Resources. The findings revealed that top managers in Türkiye's maritime industry placed the greatest emphasis on the Government and Markets, and Positioning themes. While top managers' strong awareness of global environmental challenges signalled the industry's awareness of sustainability issues, the fewer occurrences of keywords under the 'Human Resources' and 'Technology' themes suggested limited attention to the working environment, required skills, and management practices. Future research can build upon this study by incorporating additional maritime industry-related magazines and publications, offering broader perspectives and deeper insights.

Keywords: *Maritime Business Administration, Strategic Management, Content Analysis, Discourse, Top-Level Managers*

1. INTRODUCTION

Companies face significant challenges in achieving future success in today's globalised and technologically advanced business landscape. Strategic management provides a framework for companies to address such challenges, enabling them to devise action plans that ensure market survival and competitive advantage. By focusing on business strategy, companies address issues related to continuity and competition; a business' capacity to achieve a competitive advantage and distinguish itself from competitors relies on its commitment to strategic management principles. (Barca, 2005; Kaplan *et al.*, 2014).

Strategic management encompasses planning, implementing (Bourgeois *et al.*, 1984; Hart *et al.*, 1994) and reviewing an organisation's strategy (South, 1981). All modern organisations utilise strategic management and associated tools to pursue the desired level of performance. Strategic management processes offer significant benefits for an organisation, including the ability to support organisational continuity, set direction, focus on critical issues, highlight environmental conditions and gain a competitive advantage (Bryson, 1988; Kotter *et al.*, 1992; Collins *et al.*, 2004; Betz, 2010). These advantages are universally sought across all industries, albeit with varying degrees of necessity and diverse applications depending on the specific industry context (Foss *et al.*, 1995). The maritime industry is among the sectors profoundly impacted by global shifts (Notteboom, 2004), necessitating that decision-makers enhance and adapt their strategic management practices to navigate these challenges effectively.

As globalisation promotes trade expansion among nations, maritime transportation remains a crucial mode of international commerce, with a significant portion of global trade still transported by sea. In 2023, total global maritime trade volume increased by 2.6% annually to 12.3 billion tonnes, supported by solid growth of 4.8% in seaborne major bulk cargo trade and 3.0% in oil trade (İMEAK DTO, 2024). The ability to transport large volumes of cargo in a single operation, along with opportunities for cost savings and reduced transport-related risks, has made maritime transport a preferred choice (Saban *et al.*, 2009). However, the economic structure of maritime transport is quite complex, as it operates internationally and requires substantial capital investment (Mitroussi, 2013). Additionally, global economic and political changes, demographic shifts, the transition to low-cost production, environmental regulations, and energy supply and demand fluctuations all impact maritime transport. In this context, it is evident that strategic management activities are significant in ensuring the continuity and success of maritime enterprises operating within dynamic and fluctuating micro and macro environmental conditions.

Despite the crucial role of strategic management in the maritime industry, there remains a lack of research on the strategic management practices of its decision makers. Previous research at the intersection of strategic management and the maritime industry investigated corporate social responsibility and maritime regulations (Fasoulis, 2021), corporate visions and strategies relevant to sustainability (Kronfeld-Goharani, 2018), technological advancements and market demand (Hermann, 2017) as well as the effect of leadership and talent on performance (Pantouvakis *et al.*, 2020). Research findings indicated several strengths and areas of improvements within the industry. For instance, corporate social responsibility practices of the maritime stakeholders showed adequate coverage in human rights, labour, organisational and environmental governance. However, there is room for improvement in the areas of fair operating practices, consumer treatment, and community involvement (Fasoulis, 2021). In terms of regional regulations and technology adaptation of the industry, findings indicated an opposition to such regulations. Despite this, the industry stakeholders had to embrace environmental technologies. If industry players failed to adapt, regulations such as Sulphur Emission Control Area would lead to higher fuel prices (Hermann, 2017), thereby increasing the operating costs of marine transport companies. In a similar vein, the discourse analysis of Kronfeld-Goharani (2018) revealed a shift from a voluntary to mandatory commitment to blue economy due to increased global pressure towards sustainable practices. Similar to Hermann (2017), Kronfeld-Goharani (2018) observed a reluctant uptake of a sustainability-focused mindset among the industry stakeholders. Nonetheless, the stakeholders adjusted their operational and strategic decisions. The findings identified that improving and maintaining public image, as well as avoiding fines and lawsuits as some of the key motivations for adopting this mindset. Finally, research on the impact of leadership and talent on the maritime industry's sustainability performance, taking organisational culture into account, revealed that talent management has a greater influence on sustainable performance in the industry compared to leadership. Furthermore, organisational culture moderates the relationship between talent management and sustainability (Pantouvakis *et al.*, 2020). Overall, the authors note an increasing global focus on sustainability issues in the strategic management and the maritime industry literature.

While global research output shed light on the maritime industry's strategic management practices, there remains much to explore in the context of Türkiye. Accordingly, this study explores the medium- and long-term business behaviours and strategic management practices within Türkiye's maritime industry. Through an in-depth analysis of the narratives of top managers, the authors offer a detailed examination of top-level managers' perceptions of strategy and strategic management. Data for this research were sourced from the official publication of the İMEAK Chamber of Shipping, culminating in 68 interviews conducted between 2020 and 2024. The interviews involved various stakeholders within the industry, including representatives from ports, shipbuilding and design, transportation and logistics, insurance, and ship inspection and control. This study offers contemporary insights into top-level managers' perceptions of strategy and strategic management, exploring their strategic management practices through discourse. Framed within the recent economic conditions of the maritime industry and analysed through the lens of strategic management, the findings further shed light on the status of maritime businesses in Türkiye.

The paper is structured as follows: it begins with an overview of the strategic management literature, followed by surveying the current state of the maritime industry

and related research in the strategic management field. Next, the sampling and analysis methods used in the study are explained. The findings are then presented. Finally, the paper concludes with a summary of the discussions and recommendations.

2. LITERATURE REVIEW

Strategic management is about "making a firm or an organization perform and about maintaining the organization's or firm's ability to perform" (Sminia, 2021, p. 1; Sminia *et al.,* 2012). This definition highlights four core aspects of strategic management. First, strategy is inherently linked to performance, addressing performance-related issues. Second, strategic management recognises the critical role of specific abilities or competencies in achieving performance. Third, maintaining performance is central to strategic management. Finally, the scope of strategic management is at organisational and firm level at most. This indicates that strategic management typically does not cover national and global strategies.

The focus of strategic management on organisations and firms, along with its concern for their ability to perform, have resulted in the emergence of a robust research field, building upon and advancing its three elements: "its roots in practice, its methodology, and its theoretical underpinnings" (Bowman *et al.,* 2002, p. 31).

Indeed, several strategy theories have emerged over the years. For example, the marketing concept offered an initial foundation for the practice of strategic management, encouraging strategists to perceive the environment as a marketplace of customers with needs and desires to be fulfilled (Sminia, 2021). From a practice viewpoint, Bowman *et al.* (2002) documented the changes in the strategy practice, beginning with financial planning in the 1950s, followed by long range planning in the 1960s. These were followed by further changes to practice. The 1970s saw the rise of strategic planning, heavily influenced by forecasting methods. Building on these, strategic management emerged in 1980s, including both strategic planning and implementation.

Successful strategic management plays a vital role in the maritime industry. Consider shipping as an example. It is an essential mode of transport (Duru *et al.,* 2011), playing a crucial role in the global economy (Stopford, 2009). Several characteristics such as capital intensiveness (Omrani *et al.,* 2015), high cyclicality (Chen *et al.,* 2012; Chistè *et al.,* 2014; Nielsen *et al.,* 2014), and non-linear, uncertain and behavioural factors (Duru, 2016; Greenwood *et al.,* 2015) are commonly observed. Beyond shipping, intense competition is a defining characteristic of other maritime sectors, such as among ship brokers (Nowińska, 2019), shipbuilders, short-sea shipping companies and terminal operators (Lee *et al.,* 2014).

The 2008 financial crisis significantly affected the industry stakeholders; some shipping lines adopted capacity strategies, leading to further market instability and using alternative routes such as the Cape (Notteboom *et al.,* 2016). Container liners adopted slow steaming on a larger scale, which has turned into the new normal in the industry (Gökmen, in press). Following the crisis, the industry experienced further shocks. For instance, global seaborne trade growth in ton-miles increased rapidly after the financial crisis, followed by a steady decline. The COVID-19 pandemic resulted in a sharp decline in seaborne trade. This was followed by a sharp increase (UNCTAD, 2023). Trends in the world economy continued shaping global seaborne trade; the growth is currently stagnating (UNCTAD, 2024).

Today's complex and challenging environment pushes decision makers in the maritime industry to act on emerging issues; strategy is a make-or-break for maritime organisations and firms, more so now than before. Their survival depends on successfully crafting, pursuing, and implementing strategies. In unpredictable, rapidly changing, and highly competitive markets, engaging in innovative and divergent strategic thinking across various organisational levels is essential for establishing and maintaining a competitive edge (Liedtka, 1998, in Graetz, 2002).

The maritime industry has traditionally been quite secretive; only in recent years have industry stakeholders become more inclined to share data (Vermeulen, 2013). Therefore, despite the importance of strategic thinking and decision-making in the maritime industry, stakeholders' secretive approach to data sharing has largely kept their strategic management practices unknown to outsiders. The authors interpret the industry stakeholders' willingness to share data as an indicator for increased and enriched research opportunities in strategic management.

Strategic maritime management is a developing field akin to the early phase of strategic management. Current literature offers some insights into the industry's governance and strategy through two main research streams: one focusing on the internal governance structure, with an emphasis on the network perspective, and the other on developing strategic capabilities for networked maritime organisations to enhance long-term competitiveness (Wang *et al.,* 2018). Only a limited amount of past research sheds light on industry stakeholders' strategy and planning practices (e.g., Koufopoulos *et al.,* 2005). The thought process behind strategy-making among these stakeholders is still underexplored.

In the following sections, the authors present available information on strategic management in the maritime industry, beginning with industry practices in strategy, followed by scholarly contributions to theory.

2.1. Management in the Maritime Industry

The maritime industry consists of a diverse range of sectors that have emerged and evolved over the years in response to national and international trade needs. One reason for the sectorial diversity within the industry stems from the scale of the shipping business. At its most basic level, the maritime industry involves the task of moving X amount of cargo from point A to point B. Several sectors, such as road and railway transportation, terminal and port operation, shipbuilding and education, contribute to the completion of the task—transportation of cargoes by sea. These sectors operate in closely related yet distinct business environments, providing unique services and products. furthermore, sectoral diversity in the industry is increased by the consolidation and handling requirements of different cargo types, such as bulk, break bulk, containerised cargo.

Managerial challenges such as cybersecurity, quality of service and customer satisfaction are common to both

the maritime industry and other industries. However, the maritime industry also faces unique management challenges specific to its operations. Examples of such unique challenges include port congestion and infrastructure limitations (Lin *et al.,* 2022), complex local and international regulations, including competition laws and environmental standards (Akyar *et al.,* 2024), challenging working conditions and seafarer shortage (Thai *et al.,* 2013), chokepoints in maritime routes, blockages, seasonal variations in wind and sea currents (Rodrigue, 2020) and the lack of standards to support technological advancements, such as blockchain technology (Liu *et al.,* 2023).

Most of these unique challenges share one key characteristic: they are external factors that are beyond the control of the maritime. Consequently, managers in the industry must navigate complex and intertwined socially constructed realities (e.g., regulations and laws) and natural realities (weather conditions, Arctic region challenges). As a result, managers in the maritime industry are required to monitor the external environment more closely than their counterparts in other industries.

Several strategic management tools are available to managers, with scenario planning being one that has gained traction in the maritime industry in recent years. This is not surprising, considering the tool's ability to scan the external environment and effectively guide managers into thinking plausible future outcomes.

2.2. Maritime Industry and Strategic Management in Practice

Only a few scientific research thoroughly examined the strategic management practices of the maritime industry stakeholders. According to Koufopoulos *et al.* (2005), strategic planning has increasingly moved from informal to formal approaches over the decades, with most European companies embracing structured planning processes. Greek shipping companies were found to examine both internal and external factors affecting their businesses. The authors also noted limited use of advanced strategic planning techniques, such as scenario planning. Following their study, Vermeulen (2013) contributed to knowledge, stating that the planning thoroughness varied by market segment; liner companies were more inclined to conduct environmental analysis than bulk shippers, and tanker companies were more proactive in planning than dry bulk companies. Similar to Koufopoulos *et al.* (2005), Vermeulen (2013) reported that only a small group of industry stakeholders used specific analytical tools like SWOT.

However, industry stakeholders have adopted various strategy-making tools in the past decade. For example, some have embraced a vision/goal-oriented approach, conducted SWOT analyses more frequently, and practised scenario planning to anticipate future challenges (Wu *et al.,* 2020). While the extent to which adopting such approaches and tools has benefited stakeholders is an important question, it falls outside the scope of this paper.

In recent years, scholars started investigating the strategic discourse of the maritime industry stakeholders using content analysis to progress the strategic maritime management field. Karagiannis *et al.* (2022) investigated the corporate social responsibility agenda of the maritime sector by conducting a content analysis of 90 sustainability reports. Their findings revealed that many maritime organisations remain focused on meeting regulatory requirements rather than adopting proactive CSR strategies. Port operators were an exemption in this finding. In a longitudinal study, Wang *et al.* (2021) inquired into the industry stakeholders' sustainability related communications on Twitter, using the 2030 Agenda and Sustainable Development Goals (SDGs) as a normative framework. The content analysis findings revealed a noticeable shift in their sustainability communications: the stakeholders' earlier social media presence focused on communicating core industry responsibilities, using keywords like 'trade,' 'infrastructure', 'growth', and 'investment'. In contrast, later Twitter communications have expanded significantly, incorporating keywords such as "women," "biofuel," "carbon," and "partnership." The authors interpreted this change as an indicator of broader engagement and shifted focus on different SDGs. Finally, Yashalova *et al.* (2023) looked into the corporate vision statements of the maritime logistics company. They found that the content of vision statements varied but also shared similarities in areas such as demonstrating business-related activities, attention to customers and sustainability issues.

Despite the increasing transparency of the industry, there remains room to explore stakeholders' approaches to strategic thinking, development, and implementation. This knowledge gap is particularly significant in Türkiye, which hosts dynamic seaborne trade activities and a growing number of terminal operations. Accordingly, the authors aim to explore the industry stakeholders' perceptions, approaches and practices related to strategy through a comprehensive analysis of documented interviews, employing content analysis. The following section presents the research method to the reader.

3. METHOD

Qualitative research represents one of the processes of knowledge production, which aims to gain insight into the lifestyles, narratives, behaviours, organisational structures and social changes of individuals and communities (Strauss *et al.,* 1990). The motives, preferences and decisions of managers who are effective in the strategic behaviours of businesses can be better understood with qualitative methods (Ketchen *et al.,* 2008). Accordingly, this study employs a qualitative research design, utilising content analysis (Elo *et al.,* 2008; Mayring, 2015; Morgan, 1993; Neuendorf, 2016).

Content analysis was mainly selected because it facilitates an in-depth and detailed exploration of the discourses of top-level managers in the maritime sector (e.g., Phillips *et al.,* 2007). In the course of structuring the research, it was assumed that data and insights could be obtained from the discourses of top managers in order to gain an understanding of the strategic management paradigm of the Turkish maritime industry. In this context, another reason for employing the content analysis method in the study was due to its frequent use in social sciences research and its ability to provide insight into the general trend within the scope of the subject matter, thereby guiding subsequent academic studies (Ültay *et al.,* 2021). The existence of studies analysing the discourses of senior executives constituted another methodological basis of the study (Ekmekçi *et*

al.; Kılınç *et al.*, 2020; Sözüer, 2022).

The authors followed a structured approach to collecting by systematically reviewing the literature. The authors selected Deniz Ticareti Dergisi as the primary data source. Deniz Ticareti Dergisi is the official publication of İMEAK Deniz Ticaret Odası (İstanbul & Marmara, Aegean, Mediterranean, Black Sea regions Chamber of Shipping), which is the flagship organisation of the Turkish maritime industry. Deniz Ticareti Dergisi, which was first published in 2015, contains a variety of content, including the latest news from different sectors of the maritime industry, interviews with executives, academic articles, and sections on the activities of the IMEAK Chamber of Shipping and evaluations of the assembly sessions.

The authors focused on the interviews in the Deniz Ticareti Dergisi published between January 2020 and October 2024. The following process was followed: The interviews were identified and included based on inclusion and exclusion criteria. Interviews that were not affiliated with any organisation and were conducted as personal life stories were not included in the sample. The authors also observed that some enterprises or managers were interviewed multiple times throughout the years and decided to include them in the analysis since each interview provided valuable and relevant information. Following the inclusion and exclusion process, 68 interviews were identified as suitable for the study's scope.

The authors observed a significant gender imbalance among the interviewees, with 61 men and 7 women out of 68 interviews. These interviews spanned 12 maritime-related sectors and involved a variety of senior managerial positions (refer to Table 1 for details). A review of the participants' positions revealed that having senior executives' interviews in the study, whose strategic management discourses are pivotal and who hold significant representation and decision-making powers, ensured a strong alignment between the research objectives and the data collected.

Following the data collection and inclusion and exclusion criteria process, the authors familiarised themselves with the interview excerpts. To identify the strategic discourses of the top managers, the authors developed a strategic management discourse dictionary compiling keywords from an eminent book on strategic management by Pettigrew *et al.* (2001). The keyword selection stage followed a structured process, where the authors first identified 426 keywords and further reduced this number to 56 after careful elaboration. The elaboration process involved reviewing the keywords and retaining those that encapsulated the meaning of other, more specific terms. The authors then conducted a deductive content analysis using the complied dictionary using MAXQDA 2020. Excerpts containing the identified keywords were included in the coding process. Repeated phrases with the same meaning within a single interview were counted only once. Consequently, 454 statements featuring "strategy" and other relevant keywords were identified and coded. Examples of the coding are provided in Table 2.

Table 1. Data inventory

Source	Deniz Ticareti Dergisi
Scope	58 Issues (between January 2020 and October 2024)
Number of interviews	68
Interviewees' roles	Chairperson (13), Vice Chairperson (5), Board Member (2), General Manager/CEO (22), Department Manager (10), Assembly/ Commission Chairperson (4), Rector (1), Deputy Minister (1), Secretary General (1), Ambassador (1), Founder (8)
Represented sectors	Machinery spare parts and fuel supply (12), Shipbuilding and design (11), National maritime and professional organisation (10), Maritime transport and logistics (9), Ship inspection and control (6), International maritime and professional organisation (5), Port management (5), Governmental organisational (3), Fair organisation (2), IT/Technology (2), Insurance/ P&I (2), University (1)
Total Word Count	98.215
Number of coding	454

Source: Authors' data collection

The main limitation of this research is its reliance on a single journal. The authors' data collection was limited to the interviews published in the past four years. Future studies can increase this number further for an even more comprehensive analysis. Despite the authors' meticulous efforts and careful data extraction and analysis, the analysis and resulting findings were inherently influenced by the interview questions the journal's editorial preferences shaped.

4. FINDINGS AND DISCUSSION

The authors' data analysis resulted in identifying 454 excerpts. Following this, they analysed the use of keywords across different years. Analysis revealed 87 coded excerpts in the journal issues in 2020, 102 in 2021, 142 in 2022, 77 in 2023, and 46 in 2024. This result shows an increase in the number of coded excerpts until 2023, with higher coding frequencies observed during the years when the effects of the COVID-19 pandemic were most pronounced. This trend suggests an increased emphasis on strategic management and its associated discourses in response to crises like the global coronavirus pandemic.

The 454 excerpts coded with 56 terms were summarised and detailed under six themes to facilitate analysis and ensure accuracy. The obtained theme and term pattern are presented in Table 3.

Table 2. Example keywords and coded excerpts

Keyword	Excerpt
Aim	With the awareness that the future of our country lies in the seas and maritime, we are carrying out various activities to ensure that maritime education is provided at the most advanced level. In maritime education, we aimed to raise a seafarer population with full professional knowledge and experience, capable of making critical decisions, able to express themselves in English and willing to practice this profession for a long time." (Ünal BAYLAN- Directorate General for Maritime Affairs- 2021 May Issue)
Forecast	"Drawing on SGS's experience and leadership in sustainability, our ESG Assurance Systems offer a comprehensive range of end-to-end services to help organisations reduce risks in their supply chains, implement better and more efficient processes, address stakeholder concerns and achieve their sustainability goals. We estimate that this service will become much more prominent in the coming period. In Türkiye, we assume that industrial and economic recovery will begin by 2022 in synchronisation with the rest of the world. The revival of tourism, one of Türkiye's most important sources of foreign currency income, will undoubtedly play a major role in this recovery. (Nadin Haçerestunç- SGS Türkiye-2021 July Issue)
Competition	I see that we are on the rise again in the new construction sector, but our speed is a little slow; one of the biggest reasons is that our competitive power with the Far East is weak. Their workforce capacity is substantial, and they are one step ahead of us in planning and programme. As a shipbuilding engineer, I can say that if suitable investments are continued, it will not be a dream that is too distant for us. (Ömer OĞUZ-Leo Marine-December 2021)
Conflict	"In our charter agreements and relations with the charterers, serious problems and disagreements about fuel are experienced from time to time. Problems have also started to occur in responsibility/authority sharing." (Ender KESKİN- Transal Shipping-2022 June Issue)

Source: Authors' data collection
Note: While the analysed interviews were in Turkish, the excerpts presented in the table are translated into English by the authors for demonstration.

Table 3. Strategic management themes

Theme	Code
Government and Markets	Collaboration, Currency, Environment, Laws and Contracts, Stakeholder, Politics, Multinational, Privilege, Market
Positioning	Diversification, Customer Orientation, Entry Cost, Threat, Opportunity, Trend, Competition, Aim, Forecasts, Lifecycle, Advantage
Performance	Quality, Cost, Value, Mistake, Continuity, Social Performance, Finance, Strengths, Weaknesses, Price
Growth	Acquisition, Strategy, Growth, Downsizing, Planning, Scenario, Entrepreneurship, Investment, Share, Resource
Technology	Science, Knowledge, Creativity, Research, Technology, Learning, Change
Human Resources	Manager, Talent, Expert, Responsibility, Employment, Conflict, Emotion, Behaviour, Faith

Source: Authors' data collection

Frequency values and distributions of the themes according to this coding structure are shown in Table 4. The findings demonstrate that six strategic management themes are distributed across approximately 8% to 26% of the total 454 excerpts, reflecting a balanced yet diverse emphasis on various aspects of strategic management. Based on the thematic analysis, "Government and Markets" emerged as the most prominent theme, while "Human Resources" had the fewest codes. This finding highlights the maritime industry's cyclical nature, dependency on derived demand, and constant interaction with micro and macro environmental factors. These characteristics likely drive the emphasis on "Government and Markets," underscoring the industry's reliance on regulatory frameworks, policy decisions, and market dynamics as critical elements influencing strategic management practices.

Table 4. Distribution of strategic management themes

Theme	Frequency	Share (%)
Government and Markets	119	26,2
Positioning	100	22
Performance	78	17,2
Growth	75	16,5
Technology	46	10,1
Human Resources	36	8
Total	454	100

Source: Authors' data collection

Under the 'Government and Markets' theme, the most coded term was 'Environment'. The issue of sustainability, which is at the core of the energy, economy and environment nexus, represents a pivotal concern for governments, intergovernmental organisations, and numerous non-governmental organisations. The maritime industry forms the backbone of global trade, carrying a

substantial responsibility for carbon emissions and negative environmental impacts. Related to these, the authors observed that senior executives working in different maritime industry sectors frequently emphasised issues such as decarbonisation, alternative fuels and EU Emissions Trading System (EU ETS) in their interviews. In parallel with this situation, the authors further identified that legal regulations such as the Ballast Water Management Convention, IMO 2030 targets, and the Emission Control Area (ECA) are frequently emphasised. The discourse of senior executives in Türkiye's maritime sectors reveals a strong awareness of critical global environmental challenges. This acknowledgement by top industry leaders indicates the maritime industry's interest in tackling these challenges effectively, steering the sector toward a sustainable and resilient future.

While reviewing the codes, the authors noted that the codes for 'Aim' and 'Forecast' were often highlighted under the theme of 'Positioning'. This indicates that senior executives had the opportunity to explain the objectives of their organisations and often shared their predictions for their sectors' future. This observation also highlights the importance of industry magazines such as Deniz Ticareti Dergisi for managers to share their company's expectations for the future. The 'Social Performance' code was often highlighted in another prominent theme, 'Performance'. This highlight shows that, in parallel with the growing importance and development of the maritime industry, maritime companies tend to contribute to the welfare and needs of society through various social responsibility projects, and senior managers emphasise this awareness in their discourses. Moreover, on the theme of "Growth", it was revealed that top managers of the Turkish maritime industry were keen to share with readers the development of their investments, detailing their investments in shipbuilding, equipment purchases and investments in clean and innovative technologies. Accordingly, upon examination of the frequently emphasised 'Finance' code under the theme of 'Performance', it is evident that senior managers gave importance to highlighting the challenges encountered in accessing financial resources, the adverse implications of the dearth of specialisation in maritime finance and the necessity for maritime banks.

The authors observed that the 'Human Resources' and 'Technology' themes received less emphasis than other strategic management themes. Specifically, within the 'Human Resources' theme, managers predominantly focused on employment policies, with minimal discussion of other critical aspects such as the working environment, required skills, and management styles. This limited emphasis suggests potential areas for more profound exploration and strategic development. This aspect also stands out as an issue that requires attention.

The analysis of the interview data, grounded in two strategic management schools of thought—the Position School, which emphasises the external environment, and the Resource-Based approach, which focuses on the internal environment (Mintzberg *et al.*, 2020)—reveals that top managers in the maritime industry predominantly align their discourse with the Position School. This finding indicates the industry's strong focus on external factors, such as global policies, regulations, and competitive positioning.

5. CONCLUSION

In today's global business environment, many companies are focused on continuous improvement to establish themselves and compete effectively in the market. This development process must be carefully managed, planned, and executed, which can only be achieved through effective strategic management. The importance of strategic management analysis in maritime trade, a key component of global trade, is growing steadily.

In this study, the authors aimed to understand the strategic management discourse of the top managers in the maritime industry in Türkiye. The managers' discourses were investigated using deductive content analysis based on a keyword dictionary that the authors developed. By developing the dictionary, the authors have made a valuable contribution to the literature on content analysis, offering a resource that enhances the depth and scope of future research.

The interviews in the Deniz Ticareti Dergisi, which is the official publication of İMEAK Chamber of Shipping, published between January 2020 and October 2024, were explored within the six strategic management themes: Government and Markets, Positioning, Performance, Growth, Technology and Human Resources. The findings revealed that top managers in the Turkish maritime industry sectors most emphasised the Government and Markets, and Positioning themes. While top managers' strong awareness of global environmental challenges signalled the industry's awareness of sustainability issues, a lower number of codes in 'Human Resources' and 'Technology' themes indicated top managers' limited attention to the working environment, required skills, and management styles. This limited emphasis highlights potential areas for more profound exploration and strategic development, offering opportunities to address overlooked aspects and enhance organisational effectiveness.

The study contributes to the literature by identifying key areas discussed by top-level managers in interviews. The results highlight the emphasis these managers placed on certain issues, enabling the authors to frame the top-level managers' perception of strategy. The strong focus on the Government and Market, and Positioning themes were expected, given the influence of external environment and global GDP on maritime business.

However, the top-level managers appear to undermine the positive impact that effective human resources management such as talent management can make on business performance. For instance, effective talent management has been shown to positively influence sustainability-related outcomes in maritime companies (Pantouvakis *et al.*, 2020). The managers' limited attention to technology-related issues supports the view that the maritime industry is conservative in adopting new technologies or creating innovative market solutions (Koukaki *et al.*, 2020).

Effective human resources and innovation management practices appear to receive less attention in the industry. Policy development that promotes and supports the uptake of advanced technology and effective human resources management would contribute to the development of the industry. These areas of improvement, facilitated through policy implementation, are particularly important for countries and regions

aiming to align with blue growth principles (Clark, 2018; DG Mare, 2012). Policymakers would benefit from prioritising these areas to foster industry development.

Future research can build upon this study by including additional maritime industry-related magazines and publications. While the selected journal serves as a flagship publication in the country, expanding the sample could enhance the comprehensiveness of the research findings.

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Review Article

A REVIEW OF AMMONIA AS A SUSTAINABLE FUEL FOR MARITIME TRANSPORTATION

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ABSTRACT
While the maritime transportation sector plays a critical role in the global economy, it also significantly contributes to greenhouse gas emissions. This study examines the energy efficiency, technical feasibility, and environmental impacts of ammonia as an alternative fuel in maritime transportation. The contributions of regulatory initiatives, such as the IMO's (International Maritime Organization) Energy Efficiency Existing Ship Index (EEXI) and the EU's FuelEU Maritime initiative, in promoting the use of low-carbon fuels to reduce emissions are discussed. The study evaluates the chemical and physical properties of ammonia, challenges associated with its combustion and production processes, with a focus on integrating renewable energy sources for green ammonia production. Findings suggest that ammonia's low reactivity and wide availability make it a promising sustainable fuel. However, overcoming challenges such as combustion difficulties and toxicity will require technological advancements. This comprehensive analysis provides an in-depth perspective on the potential contributions of ammonia to achieving decarbonization goals in the maritime sector, as well as the obstacles that must be addressed.

Keywords: *Ammonia fuel, Decarbonization, Maritime, Sustainability, Alternative fuel.*

1. INTRODUCTION

Internal combustion engines and other energy conversion systems have significantly contributed to humanity's technological and economic development. Fossil fuels such as oil, coal, and natural gas have served as the primary energy sources for this progress. For decades, internal combustion engines and liquid hydrocarbons have worked as a compatible duo, playing a pivotal role in transportation, power generation, agriculture, and maritime shipping.

Maritime shipping, a crucial component of global transportation, supports the global economy with approximately 127,000 ships and a gross tonnage capacity of 1,600,000 (EMSA, n.d.). Despite its economic contributions, the environmental impact of maritime shipping, particularly concerning carbon dioxide and other harmful emissions, has become a significant concern. These emissions pose a threat to the sector's sustainability and necessitate the search for cleaner energy solutions. Currently, CO2 emissions from the transport sector account for approximately 24% of global CO2 emissions, while transport-related greenhouse gases constitute about 14% of global greenhouse gas emissions (Ritchie & Roser, 2024). Therefore, reducing emissions in the transport sector is a critical step in combating climate change.

The International Maritime Organization (IMO) is a United Nations agency that regulates the international maritime shipping industry. The IMO's practices establish an international framework aimed at reducing emissions in the maritime transport sector. To address this challenge, the International Maritime Organization (IMO) has implemented various regulatory measures for newly constructed and operating ships. In 2011, the Energy Efficiency Design Index (EEDI) was introduced for newbuilds, aiming to enhance energy efficiency and reduce emissions through technological solutions. This regulation encourages the adoption of energy-efficient designs in ships and is recognized as a key step toward minimizing the environmental impact of maritime shipping. The EEDI evaluates ships' energy consumption and carbon emissions, promoting the use of low-emission technologies. However, as this regulation applies only to new ships, the Energy Efficiency Existing Ship Index (EEXI) was introduced to assess the energy efficiency of existing vessels. Since 2023, ships of 400 GT and above are required to comply with EEXI standards and meet minimum energy efficiency requirements. These measures aim to enhance environmental sustainability in maritime shipping. In July 2023, the IMO finalized the first update to its GHG strategy. The original 2018 strategy set a target to reduce carbon intensity from shipping by at least 70% by 2050 and to cut total annual GHG emissions by at least 50%, using 2008 as the reference year. The 2023 update significantly enhanced the targets for international shipping, particularly aiming for a 50% reduction in GHG emissions by 2050. The revised strategy sets a 20% reduction in GHG emissions by 2030, with an aspiration to reach a 30% reduction. In the following years, the strategy targets a reduction of 70% by 2040 and 80% by 2040, ultimately aiming for net-zero emissions by 2050 or shortly thereafter (DNV, 2023; Elçiçek, 2024).

IMO 2020 Rule: Starting from 2020, the sulfur content in fuels used in the maritime industry was reduced to 0.5%. This has significantly reduced SOx emissions in the maritime sector (Sáez Álvarez, 2021).

IMO 2050 Net Zero Emission Target: The IMO has set the goal for global maritime shipping to achieve net-zero emissions by 2050 (Lee et al., 2024; Lindstad et al., 2023).

Additionally, ships over 5,000 GT are mandated to collect and regularly report energy efficiency data. If a vessel's Carbon Intensity Indicator (CII) rating is deemed inadequate, corrective actions are required from the shipowners. In alignment with climate change mitigation efforts, IMO updated its greenhouse gas (GHG) reduction strategy in 2023, targeting a 70–80% reduction in GHG emissions by 2040 compared to 2008 levels, with the ultimate goal of achieving zero emissions by 2050. Similarly, the European Union has established long-term goals for maritime transport, issuing Directive SEC (2021) 562, which aims to reduce GHG emissions by 90% by 2050 compared to 1990 levels. Achieving these targets necessitates significant reductions in CO2 emissions from the maritime sector, particularly through improving energy efficiency and promoting the use of renewable and low-carbon fuels, such as hydrogen and ammonia.

The importance of alternative fuels in the maritime sector has been reported in many studies in the literature. Recent researches suggests that alternative marine fuels could reduce CO_2 emissions by anywhere from 20% to 100%, with the exact reduction varying depending on the type of fuel used (Chai et al., 2021; Xing et al., 2021). Many similar studies aim to illuminate how alternative energy sources can play a significant role in reducing carbon dioxide emissions produced by the maritime industry, as well as the potential obstacles that may arise (Rony et al., 2023; Al-Enazi et al., 2021; Wang & A. Wright, 2021).

FuelEU Maritime is a new EU regulation aimed at reducing greenhouse gas emissions from fuels used in the maritime sector by promoting the adoption of renewable and low-carbon fuels. This initiative, a key component of the EU's "Fit for 55" package, outlines comprehensive measures to reduce the greenhouse gas intensity of maritime fuels by 2% in 2025 and up to 80% by 2050. The regulation plans to incentivize renewable and low-carbon fuels while phasing out fossil fuels. Furthermore, by 2030, passenger ships and container vessels at major EU ports will be required to meet their entire energy needs using shore-side electricity. These measures will align the maritime sector with the EU's 2030 and 2050 climate goals, significantly reducing the sector's carbon footprint (Drazdauskas & Lebedevas, 2024).

Ammonia has emerged as a promising alternative fuel for achieving zero-carbon emissions in the maritime sector. Given the need to mitigate the environmental impacts of fossil fuels and curb greenhouse gas emissions, integrating ammonia into maritime transport presents significant opportunities and challenges (Berwal et al., 2021; Herbinet et al., 2022a; Nadimi et al., 2022; Tornatore et al., 2022). This study examines ammonia's potential role in the sector concerning energy efficiency, technical feasibility, and economic sustainability, evaluating the challenges encountered and the benefits it offers. The analysis aims to provide an in-depth perspective on whether ammonia can contribute to the green transition in maritime transport.

2. AMMONIA AS AN ALTERNATIVE FUEL

Studies focusing on ammonia as a fuel reveal an increasing interest and a growing research community in recent years compared to earlier periods (Herbinet et al., 2022b). Ammonia can be converted into energy either through fuel cells or internal combustion engines. Table 1 presents the physical and chemical properties of ammonia alongside those of other fuels (Hu et al., 2023).

Ammonia is a versatile compound offering numerous industrial and environmental advantages. As a colorless gas lighter than air, it has the capacity to disperse rapidly in the environment. Since it is less dense than air, ammonia rises and spreads out rapidly, reducing the likelihood of concentrated pockets of the gas lingering in one area. This quick dispersion can minimize the risk of harmful exposure or accumulation, making it safer in certain situations compared to heavier gases that tend to settle. However, while this characteristic helps with dispersion, it also means that ammonia can spread over a wide area, requiring careful management to prevent environmental or health hazards (Asman et al., 1998). Its relatively low cost makes it a preferred compound across various industries and sectors (Chehade & Dincer, 2021). Additionally, its sharp and characteristic odor allows it to be easily detected even at low concentrations, which is a significant safety advantage. While ammonia is widely recognized globally as a fertilizer, its versatility has positioned it among the most produced chemicals in the world. Over 80% of global ammonia production is used as fertilizer, but it also finds applications in controlling nitrogen oxide (NOx) emissions in exhaust gases (Jiang et al., 2020), as a component in cleaning products (Maxwell, 2004), as a refrigerant gas (Pearson, 2008), as a solvent (Gilberg & Seeley, 1982), as a bleaching agent in the paper industry (Tornatore et al., 2022), and as a reducing agent in metallurgy (Iwamoto et al., 2022). This widespread usage and global production network make ammonia a resource that is readily available in almost every part of the world. For the maritime sector, this global accessibility of ammonia is a significant advantage.

Furthermore, ammonia's low reactivity poses less risk of accidental fires or explosions compared to other fuels, making it a safer option for storage and transport. This characteristic makes ammonia particularly advantageous in industries such as maritime shipping, where high safety standards are critical.

However, ammonia is also a toxic compound and poses serious risks to human health, especially when inhaled in large quantities. Its irritant nature necessitates careful handling (Swotinsky & Chase, 1990). Due to its alkaline properties, it is corrosive and can cause damage to metal surfaces upon prolonged contact. Special precautions must therefore be taken during its storage and transportation (Khaksar et al., 2024). Ammonia's high latent heat of vaporization requires more energy for evaporation, which limits its usability as a liquid fuel. This characteristic can lower in-cylinder temperatures, impacting combustion properties and reducing efficiency (Ryu et al., 2014).

Table 1. Physical and chemical properties of ammonia alongside those of other fuels (Hu et al., 2023)

Property	**Units**	**Ammonia**	**Hydrogen**	**Methane**	**Gasoline**	**Diesel**
Density at 1 bar, 25°C	kg/m^3	0.718	0.0837	0.667	736	849
Lower heating value	MJ/kg	18.8	120	50	44.5	45
Latent heat of vaporization	kJ/kg	1370	455	511	348.7	232.4
Boiling point	°C	−33.34	−252.7	−161.5	35–200	282–338
Specific heat capacity Cp	kJ/(kg K)	2.19	14.30	2.483	2.22	1.75
Volumetric energy density at 1 bar, 25°C	GJ/m3	11.3	4.7	9.35	33	36.4
Octane number (RON)		130	>100	120	90–98	8–15
Autoignition temperature	°C	657	500–577	586	230	254–285
Laminar flame speed	cm/s	7	351	38	58	86
Flammability limit (φ)		0.63–1.4	0.1–7.1	0.5–1.7	0.55–4.24	0.8–6.5
Stoichiometric air-fuel ratio by mass		6.05	34.6	17.3	15	14.5
Adiabatic flame temperature	°C	1800	2110	1950	2138	2300

3. AMMONIA PRODUCTION

Ammonia production is carried out globally in large-scale facilities, with an annual production volume of 240.38 million metric tons as of 2023. It is projected that production will reach 276.14 million metric tons by 2026 and 289.89 million metric tons by 2030 (Global Ammonia Annual Production Capacity, n.d.). Fig.1 shows the annual growth in global ammonia capacity (Hatfield, 2020). According to the figure, net 58 million tonnes of net capacity change had been observed during this period. This production predominantly serves the fertilizer industry but also plays a significant role in industrial and energy sectors. Among the leading ammonia-producing countries, China ranks first with a share of 31.9%, followed by Russia (8.7%), India (7.5%), and the United States (7.1%) (Ammonia's Potential Role in a Low-Carbon Economy, n.d.). These countries collectively meet a substantial portion of the global ammonia demand, showcasing their critical role in the supply chain.

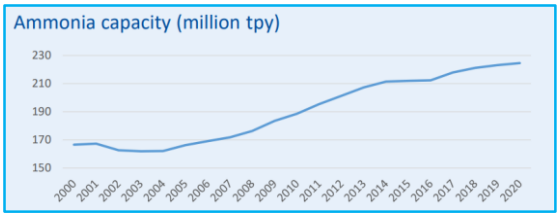

Fig. 1. Annual growth in Ammonia capacity, 2000-2020 (Hatfield, 2020)

Ammonia is produced through a catalytic reaction of nitrogen and hydrogen under high pressure and temperature. This process, commonly known as the Haber-Bosch method, accounts for the majority of global ammonia production. Nitrogen is sourced from the atmosphere, while hydrogen is typically derived from fossil fuel feedstocks, particularly natural gas. Using an iron-based catalyst, nitrogen and hydrogen combine under high-temperature (400–500°C) and high-pressure (150–250 bar) conditions to form ammonia (NH_3) (Pawar et al., 2021). However, this production process is highly energy-intensive and creates environmental impacts due to the reliance on fossil fuels. Alternative electrochemical methods show promise for ammonia synthesis, offering the potential for lower energy and water consumption compared to the electrolysis-based Haber-Bosch process. Yet, these methods have not achieved the technological maturity required for commercial-scale implementation.

To mitigate the environmental impact of ammonia production and transition toward a more sustainable process, the integration of renewable energy sources has become increasingly important. Renewable resources such as wind and solar energy can be utilized to produce green hydrogen via electrolysis. This green hydrogen can replace fossil fuel-based hydrogen, significantly reducing the carbon footprint of ammonia production. Additionally, emerging electrochemical methods powered by renewable energy could provide a sustainable alternative to the energy-intensive Haber-Bosch process, enhancing both economic and environmental efficiency (Zhang et al., 2020).

Solar energy holds significant potential as a renewable energy source for ammonia production. Electricity generated from solar energy can be used to produce green hydrogen via water electrolysis, which can then be combined with nitrogen to produce ammonia sustainably. Research indicates that the cost of producing green ammonia currently ranges between $580 and $641 per metric ton of NH_3 (Kakavand et al., 2023). Projections suggest that the global cost of green ammonia production could decrease to $370–$450 per metric ton of NH_3 by 2030 and to $285–$350 per metric ton of NH_3 in optimal regions by 2050 (Fasihi et al., 2021).

In addition to solar energy, wind energy also holds great potential in the field of ammonia production and is considered a complementary resource for sustainable energy transitions. Both offshore and onshore wind farms offer significant opportunities for ammonia production systems, providing strategic solutions for energy storage and balancing needs. Studies have demonstrated that wind energy-supported ammonia production enhances energy efficiency, economic feasibility, and reduces carbon emissions. For example, Morgan et al. highlighted that ammonia production powered by wind turbines in isolated regions reduces reliance on diesel fuel and lowers costs (Morgan et al., 2014). Similarly, Motta et al. identified solid oxide electrolysis as the most promising technology for ammonia production supported by offshore wind energy, emphasizing its long-term competitiveness (Díaz-Motta et al., 2023).

Hydropower is another renewable energy source offering sustainable and environmentally friendly solutions for ammonia production. Hydropower generates electricity through the kinetic energy of water flowing from dams, which can be used for hydrogen production and ammonia synthesis. Studies indicate that hydropower-supported ammonia production costs approximately $400 per ton in facilities with a capacity of 200 tons/day (Rivarolo et al., 2019). Since this process is entirely renewable, it is environmentally friendly and can be enhanced with various technologies to improve efficiency.

Geothermal energy, derived from underground heat, can also be utilized for electricity generation and subsequently applied to ammonia production (Shamsi et al., 2024). Economic analyses of green ammonia production systems using geothermal resources show unit costs of $74.57/GJ and an annual total cost of $123 million per year. Geothermal-based systems provide high energy efficiency and environmental benefits, though costs can vary depending on system size and efficiency levels. Both geothermal and hydropower have significant potential to enhance the sustainability of ammonia production.

The integration of renewable energy sources into ammonia production is critical for both environmental sustainability and economic feasibility. Resources such as solar, wind, hydropower, and geothermal energy can reduce dependence on fossil fuels in ammonia production, significantly lowering carbon emissions. These methods, supported by green hydrogen production, not only improve environmental outcomes but also have the potential to enhance energy efficiency and reduce long-term costs. Research suggests that innovative systems incorporating these resources can offer competitive solutions for ammonia production. However, factors such as technological maturity, infrastructure requirements, and regional resource potential must be carefully considered in this transition. Renewable energy-based ammonia production represents a crucial step toward achieving clean energy goals.

4. ENGINE AND COMBUSTION CHALLENGES

Although alternative methods such as fuel cells are available for energy recovery, the combustion of ammonia in internal combustion engines emerges as a significant approach for energy production. The combustion of ammonia, either in its pure form or as a blend with other fuels, holds particular importance due to its energy production potential and the complexity of the chemical and thermodynamic processes involved in internal combustion engines. However, the use of

ammonia in internal combustion engines presents technical challenges due to its low combustion rate and weak reactivity. Additionally, the formation of nitrogen oxides (NO_x) as by-products during the combustion process poses a significant environmental concern. Therefore, a comprehensive examination of the scientific principles and technical phenomena associated with the use of ammonia in internal combustion engines is crucial. This understanding will be essential for evaluating the potential of this innovative fuel and optimizing its application.

4.1. Ignition Delay

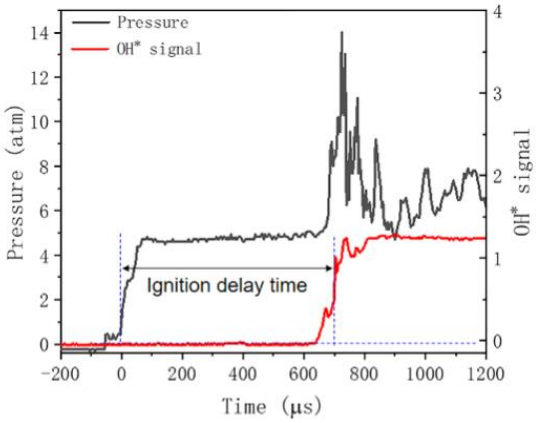

Fig. 2. Ignition delay definition for ammonia–methane/air mixture (Xiao et al., 2020)

Ammonia presents challenges in its use within internal combustion engines due to its low combustion rate and high ignition temperature. In high-pressure compression ignition systems, such as diesel engines, the low reactivity of ammonia prolongs the ignition delay period, which directly impacts engine performance (Reiter & Kong, 2008). Ignition delay refers to the time interval between fuel injection into the cylinder and the onset of combustion, a process that significantly influences the thermodynamic efficiency of the engine and exhaust gas emissions. Fig. 2 indicates the definition of ignition delay time (Xiao et al., 2020). The figure shows the typical pressure curve and ignition time, which illustrates the definition of the ignition delay period.

Ammonia may cause higher ignition delays because it requires high-energy bonds and lower ignition temperatures. This can affect the efficiency and performance of the engine, necessitating specific adjustments for engines operating on ammonia (Kurien & Mittal, 2022; Huo et al., 2024).

The combustion processes of ammonia are highly temperature-dependent. At sufficient temperatures, increased heat reduces ignition delay and facilitates combustion. However, ammonia's requirement for a high ignition temperature can hinder ignition under low-temperature conditions. B. Wang (2023) and Wang, et al. (2023) reported that gradually increasing the ammonia proportion in a fuel blend significantly extends ignition delay. In contrast, X. Wang et al. (2024) demonstrated that factors such as ammonia vaporization, increased premixed ammonia equivalence ratio, and reduced ambient oxygen concentration can further prolong ignition delay during the combustion of n-heptane fuel. To address these challenges, Zeng et al. (2024) investigated various injection strategies, aiming to optimize the combustion process through methods such as staged injection and adjusted injection timing. Additionally, Okumuş et al. (2024), in a parametric study, suggested that increasing the compression ratio of diesel engines helps reduce ignition delay, presenting this finding as a potential solution to improve combustion performance.

4.2. Laminar Burning Velocity

The laminar burning velocity is a fundamental parameter that describes how a planar flame propagates through a stationary, unburned mixture under specific pressure and temperature conditions. Thus, while a fuel with a higher laminar burning velocity is expected to facilitate faster combustion in an engine, fuels like ammonia with low laminar burning velocities may result in slower combustion processes. In ammonia-diesel blends, the laminar flame speed is influenced by several factors, including the fuel-oxygen mixture ratio, in-cylinder temperature and pressure conditions, mixture homogeneity, the presence of additives, oxidizer type and concentration, and turbulence levels within the engine.

Wei et al. (2024) explored the use of methanol to improve the low laminar burning velocity of ammonia. Methanol, due to its high reactivity, enhances ammonia's combustion performance by producing H, OH, and O radicals during combustion. Their study demonstrated that the addition of methanol significantly increased the laminar burning velocity of the ammonia/methanol blend and improved combustion efficiency while limiting carbon emissions. Similarly, (Xiao & Li, 2022) investigated dimethyl ether (DME) and found that mixing DME with ammonia positively affected the laminar burning velocity. The addition of DME improved ammonia's burning rate through its chemical kinetics and thermal effects, enabling more efficient and lower-emission combustion.

Among the most extensively studied methods in the literature to enhance ammonia's combustion properties is blending it with hydrogen. Hydrogen's high reactivity significantly contributes to increasing ammonia's laminar burning velocity. Ammonia-hydrogen blends allow for more efficient combustion by accelerating the burning process, as evidenced by several studies (Jamrozik & Tutak, 2024; B. Wang, Yang, et al., 2023; N. Wang et al., 2024; Y. Wang et al., 2021).

5. CONCLUSION

Ammonia is emerging as a promising alternative fuel in the maritime industry, aligned with global sustainability goals and regulations aimed at reducing greenhouse gas emissions. Its unique chemical properties and the potential for integration with renewable energy-based production methods make it a significant component in reducing the carbon footprint of maritime transport. However, technical and safety challenges such as low laminar burning velocity, ignition delay, and toxicity highlight the need for targeted technological innovations to optimize ammonia use. The incorporation of hydrogen and other additives offers an important solution for enhancing combustion performance and

reducing emissions. Furthermore, integrating renewable energy sources into ammonia production is critical for improving environmental sustainability while lowering costs. In the transition to low-carbon fuels, ammonia provides a viable path to achieving zero-emission targets in the maritime sector. However, the success of this transformation depends on continued research, investment, and infrastructure development.

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